XIV. *Contributions to the History of Explosive Agents.*

By F. A. Abel, *F.R.S., Treas. Chem. Soc.*

Received March 9,—Read April 15, 1869.

The degree of rapidity with which an explosive substance undergoes metamorphosis, as also the nature and results of that metamorphosis, are, in the greater number of instances, susceptible of several modifications by variations of the circumstances under which the conditions essential to chemical change are fulfilled. Gun-cotton furnishes an excellent illustration of the manner in which such modifications may be brought about. If a loose tuft or large mass of gun-cotton-wool be inflamed in open air by contact with, or proximity to, some source of heat, the temperature of which is about 135° C. or upwards, it flashes into flame with a rapidity which appears almost instantaneous, the change being attended by a dull explosion, and resulting in the formation of vapours and gaseous products, of which nitrogen-oxides form important constituents. If the gun-cotton be in the form of yarn, thread, woven fabric or paper, the rapidity of its inflammation in open air is reduced in proportion to the compactness of structure or arrangement of the twisted, woven, or pulped material; and if it be converted by pressure into compact masses, solid throughout, the rate of its combustion will be still further reduced. If to a limited surface of gun-cotton, when in the form of a fine thread or of a compactly pressed mass, a source of heat is applied, the temperature of which is sufficiently high to establish the metamorphosis of the substance but not adequate to inflame the products of that change (carbonic oxide, hydrogen, &c.), the rate of burning is so greatly reduced that the gun-cotton may be said to smoulder without flame, as shown by me in a communication to the Royal Society in 1864*; the reason being that the products of change, which consist of gases and vapours, continue, as they escape into air, to abstract the heat developed by the burning gun-cotton so rapidly that it cannot accumulate to an extent sufficient to develope the usual combustion, with flame, of the material. For similar reasons, if gun-cotton be kindled in a rarefied atmosphere, the change developed will be slow and imperfect in proportion to the degree of rarefaction, so that, even if an incandescent wire be applied, in a highly rarefied atmosphere, to the gun-cotton, it can only be made to undergo the smouldering combustion, until the pressure is sufficiently increased by the accumulating gases to reduce very greatly the rate of abstraction, by these, of the heat necessary for the rapid combustion or explosion of the substance†.

If, on the contrary, the escape of the gases from burning gun-cotton be retarded, as

* Proceedings of the Royal Society, vol. xiii. p. 213.

† Ibid. p. 205.

by enclosing it in an envelope or bag of paper, or in a vessel of which the opening is loosely closed, the escape of heat is impeded until the gases developed can exert sufficient pressure to pass away freely by bursting open the envelope or aperture, and the result of the more or less brief confinement of the gases is a more rapid or violent explosion, and consequently more perfect metamorphosis of the gun-cotton. So, within obvious limits, the explosion of gun-cotton by the application of flame or any highly heated body is more perfect in proportion to the amount of resistance offered in the first instance to the escape of the gases; in other words, in proportion as the strength of the receptacle enclosing the gun-cotton, and the consequent initial pressure developed by the explosion, is increased. Hence, while gun-cotton has been found too rapid or violent in its explosive action when confined in guns, and has proved a most formidable agent of destruction if enclosed in metal shells or other strong receptacles, it has hitherto been found comparatively harmless as an explosive agent if inflamed in open air or only confined in weak receptacles.

Other explosive compounds, and also explosive mixtures, are similarly influenced, though generally not in such various ways, by the circumstances attending their metamorphosis. Thus the rapidity of the explosion of gunpowder is modified by variations in its density and state of division, and in the degree of facility afforded for the escape of the generated gases, and consequently of the heat which is disengaged during the explosion. Mercuric fulminate may be inflamed in open air upon a piece of very thin sheet metal without indenting it, and furnishes under these circumstances a comparatively feeble explosion; but if even a very much smaller quantity be enclosed in a case or receptacle made of the same description of sheet metal, the latter will be shattered into many pieces when the fulminate is inflamed, and the explosion will be attended by a violent report.

Modifications, apparently slight, of the manner in which the source of heat is *applied* to these explosive agents, when exposed to air under circumstances in other respects uniform, suffice to modify the character of their explosions in a remarkable manner. Thus a modification of the position in which the source of heat is placed with reference to the body of a charge of gunpowder, which is only partially confined, suffice to alter altogether the character of the explosion produced. This is illustrated by the following experiment.

A cylindrical case of sheet tin, 2·5 inches diameter, 6 inches long, and open at one end to its full diameter, was inserted up to its opening in stiff clay soil, which was tightly rammed round it. The cylinder was filled with fine-grain gunpowder (about 1 lb.), and the charge was inflamed by means of a small electric fuse inserted just beneath the exposed surface of powder. The latter burned with a violent rushing sound, similar to, only of much less duration than that produced by the first ignition of a rocket, and indicating a rapidly successive ignition of layers of the powder. The canister was split open in the soldered seam, but was not thrown out of the hole. A small quantity of earth was thrown up, but fell back into the hole. A second corresponding charge of gunpowder was arranged in precisely the same manner as in the preceding experiment,

and was inflamed by means of an electric fuse placed at the *bottom* of the charge. A loud explosion was produced; much earth was thrown up and scattered, the bottom of the tin case was found in the crater produced, but the body of the case was not recovered; it had evidently been projected to a considerable distance. In this experiment the main body of the charge obviously acts, at the moment of ignition, as tamping does in a blast-hole, by presenting a resistance to the escape of the gases generated, and thus for a moment establishing the pressure essential to the violent or perfect explosion of the portion of gunpowder first inflamed, whereupon the same character of explosion extends throughout the charge.

Mercuric fulminate furnishes still more striking illustrations of the manner in which the position of the source of heat, with reference to the main body of the explosive material to be inflamed, influences the character of the explosion. In pursuing some experiments, to be presently discussed, on the explosion of gun-cotton, I was led to compare the effects obtained by the explosion of small charges of mercuric fulminate, closely confined, with those produced by comparatively large quantities of that substance freely exposed to air. In firing the latter by means of small electric fuses, I was surprised to find, on the one hand, that a small quantity (0·65 grm.=10 grains) of the fulminate produced occasionally a very much more violent explosion than was obtained with double the quantity of the same fulminate inflamed apparently in the same way, and, on the other hand, that equal quantities of the fulminate, successively inflamed, produced, in one instance, a dull report such as is well known to be furnished when flame is applied to a small quantity of freely exposed fulminate, while in the other instance a very sharp detonation was obtained, like that observed when a small quantity of closely confined fulminate is exploded. Believing that this remarkable difference of result might perhaps be caused by a variation in the force of explosion of the small electric fuse, I substituted a platinum-wire for the latter as the inflaming agent, and still the same variable results were obtained. These were at first thought to be due to a variation in the surface of the fulminate heated at one time, but they were soon traced to variations in the *position* of the source of heat. 1·32 grm. (25 grains) and 2·64 grms. (50 grains) of the fulminate, inflamed by allowing the incandescent wire just to touch the top or edge of the heap, exploded with a dull report, and produced no effect upon the thin flat plate of copper sheet upon which they rested; but about 1 grm. (15·5 grains) of the same fulminate, heaped up over the platinum-wire, produced a sharp and violent explosion, the force of which deeply indented and bent up the support of sheet copper. Equal quantities of the fulminate were made to explode feebly or detonate violently at pleasure, simply by varying their arrangement with reference to the position of the source of heat.

A few substances, of which the metamorphosis into gaseous products and vapours is developed by much less powerful impulses from without than those just instanced, the explosion of which is therefore determined by but little elevation of temperature or by

the application of slight disturbing impulses of a mechanical or chemical nature, would appear at first sight only to a small extent susceptible of modifying influences similar to the above. The direct application of but little heat, or the production of a slight increase of temperature by gentle friction or pressure, or by the development of chemical action in some very small portions of the mass, suffices to explode the chloride or iodide of nitrogen, or silver-fulminate; and the explosion of one particle developes an impulse so greatly in excess of that required to disturb the chemical equilibrium existing among the molecules of the mass, that instantaneous decomposition ensues throughout. The great proneness to change of these substances when exposed to a slight disturbing influence, is illustrated by the fact that a concussion imparted to the air in a spacious apartment in which the iodide of nitrogen has been placed, by means of a small explosion or detonation, or even by the violent slamming of a door, suffices to bring about the explosion of that substance. But even if *these* bodies be so confined that an initial resistance is offered to the escape of the gaseous products of their explosion, the violence of the detonation is greatly increased, the development of explosive force being restricted to the instant of rupture of the envelope by the compressed gases. Thus the violence of explosive force exerted by a small quantity of silver-fulminate, confined in a case of stout sheet metal, is very decidedly greater than if a corresponding quantity be enclosed in metal foil, or freely exposed to air and inflamed in the same manner. The violence of explosion of iodide of nitrogen has been found to be very decidedly increased by enclosing it in an evelope or shell of plaster of Paris, or, better still, in a case of sheet metal, while the chloride of nitrogen explodes with but comparatively little violence unless it is confined. The reputation which this substance has enjoyed of being the most violent explosive body known, appears to have been due to the fact that experiments on its explosion have always been conducted with a covering of water upon the material. Three or four drops (about 0·14 grm.=2 grains) placed in a watch-glass covered only with a thin layer of water, explode with a sharp report when touched with turpentine, and almost pulverize the glass; but similar quantities, of which the upper surfaces were exposed to air, have been repeatedly exploded in watch-glasses without breaking the latter. 2 grms. of the chloride, contained in a watch-glass, and covered with a thin layer of water, were placed upon a small solid cylinder of hard *papier maché* which rested upon paving. A violent explosion was produced by touching the chloride with turpentine, the watch-glass was pulverized and dispersed, and the cylinder was greatly shattered, fragments being projected in all directions. 4 grms. of the chloride, with the upper surface exposed to air and placed upon a similar cylinder of *papier maché*, produced a comparatively very feeble explosion; the watch-glass was broken, but the cylinder was not in the slightest degree affected, and remained undisturbed in its original position. A repetition of the experiment with 4 grms. of the chloride, enclosed by a thin layer of water, produced complete disintegration of the cylinder. It appears from these results that in the case of the chloride of nitrogen, the decomposition of which is of an instantaneous character, the resistance offered at the

moment by the layer of water acts as effectually in intensifying the force of explosion, as a thin sheet metal case does with the mercuric fulminate, or as a strong iron shell with gun-cotton or gunpowder.

The product of the action of nitric acid upon glycerine, which is known as nitroglycerine or glonoine, and which, as regards its power of sudden explosion, bears some resemblance to the chloride and iodide of nitrogen, appears to be susceptible of only two varieties of decomposition. If a sufficient source of heat be applied to some portion of a mass of this liquid in open air, it will inflame and burn gradually without any explosive effect; and even when nitroglycerine is confined, the development of its explosive force by the simple application of flame or of other sources of heat, by the ordinary modes of operation, is difficult and very uncertain. But if the substance be submitted to a sudden concussion, such as is produced by a smart though not very violent blow from a hammer upon some rigid surface on which the nitroglycerine rests, the latter explodes with a sharp detonation, just as is the case with gun-cotton. Only that portion of the explosive agent detonates which is immediately between the two surfaces brought into sudden collision; the confinement of this portion between the hammer and the support, combined with the instantaneous decomposition of the portion struck, prevent any surrounding freely exposed portions from being similarly exploded by the detonation. A similar result is obtained if *any* explosive compound or mixture be submitted to a sufficiently sharp and violent blow, but the tendency of surrounding particles to become inflamed by the detonation is in direct proportion to the rapidity of explosive action of the substances.

The practical difficulties and uncertainty which attend attempts to develope the explosive force of nitroglycerine by the agency of flame or the simple application of any highly heated body, even when the material is confined in strong receptacles (such as iron shells or firmly tamped blast-holes), appeared fatal to any useful application of the powerful explosive properties of this substance, until M. Alfred Nobel's persevering labours to utilize nitroglycerine, eventually resulted in the discovery of a method by which the explosive power of the liquid could be developed with tolerable certainty. M. Nobel first employed gunpowder as a vehicle for the application of nitroglycerine. By impregnating the grains of gunpowder with that liquid, he added considerably to the destructive force of the powder when exploded in the usual way, in closed receptacles. M. Nobel's subsequent endeavours to apply nitroglycerine *per se* were based upon the belief that its explosion might be effected by raising some portion of a quantity of the liquid to the temperature necessary for its violent decomposition, whereupon an initiative explosion would be produced which would determine the explosion of any quantity of the substance.

I have never succeeded in effecting the *explosion* of nitroglycerine by simply bringing it into contact with an inflamed or incandescent body, but the following results illustrate the manner in which a source of heat may operate in accomplishing the explosion of this substance.

A piece of very thin platinum wire, stretched across between the terminals of two insulated copper wires, was immersed in nitroglycerine; these wires were connected with a BUNSEN battery of five large cells, and a second piece of platinum-wire, similar to that immersed in the liquid, was introduced into the circuit. This was then completed, with the intervention of a long piece of platinum-wire between one of the conducting-wires and the battery. The resistance presented by this interposed platinum-wire was gradually reduced by shortening it, until ultimately the short platinum-wire not immersed in the nitroglycerine was fused. The latter was not exploded nor inflamed, nor was the wire enclosed in it fused, the heat developed in the latter being rapidly absorbed by the surrounding liquid and removed by convection. A very much thicker platinum-wire was now substituted for the thin one and immersed in the liquid; a second short piece was not interposed in the circuit in this instance, but a long platinum-wire, of the same thickness as the above, was employed, as a means of gradually reducing the resistance in circuit. When the length of this wire had been reduced to 5 inches, it was raised to bright redness; this state of things was maintained for about one minute, but the short wire in the nitroglycerine did not glow at the expiration of that period, nor did the liquid exhibit any signs of change, but the glass vessel containing it had become very warm. The long platinum-wire was then removed, and the full battery-power was passed into the short wire immersed in the liquid. After the lapse of about one minute the latter began to assume a brownish colour (like that of a solution of iron), which rapidly deepened, though no red vapours were perceptible in the upper portion of the vessel, until after the lapse of 90 seconds, when the nitroglycerine exploded with great violence.

Attempts were afterwards made to explode nitroglycerine by means of the electric spark. The bare terminals of two insulated wires were immersed in the liquid, in close proximity to each other, and it was endeavoured to pass charges from a Leyden jar; but the insulating power of the liquid prevented the passage of the spark between the immersed points. These were then arranged so as to barely touch the surface of the liquid, and powerful sparks were several times passed, but without result. The sparks from a RUHMKORFF coil with a Leyden jar attached were then allowed to pass uninterruptedly between the poles, which were just touching the liquid, the latter being splashed up by the discharges. In a few seconds the surface of the liquid darkened, and in 30 seconds it exploded.

It is evident from these results that nitroglycerine can only be *exploded* by electric agency or by direct application of any other source of heat, if the intensity of the latter, or the period during which it is applied, suffices to develope decomposition in some portion of the liquid; when once this is established, the temperature is soon raised by accumulation of heat (especially if the application of external heat be continued) until it attains the point at which explosion occurs*.

* In experiments instituted some time since on the action of heat upon nitroglycerine, I found that a small quantity (one or two drops) of pure nitroglycerine, if exposed to a very gradually increasing temperature, might be raised to 193° C. (380° F.) without the occurrence of an explosion; the liquid sustained slow decomposition

M. NOBEL has described various devices for effecting this so-called *initiative* explosion of some portion of a nitroglycerine charge, of which evidently the most successful are the explosion of a small confined charge of gunpowder, or of a large purcussion-cap, when immersed in or placed immediately over the nitroglycerine. M. NOBEL, however, classes these two modes of ignition in which an explosion or detonation is applied as the exploding agency together with various others in which the simple application of a high temperature to some portions of the nitroglycerine is proposed as the means of explo-

---

until it was entirely deprived of explosive properties. A larger quantity enclosed in a sealed tube was exposed for four days to a temperature of 100° C. without exploding. At the expiration of that period the liquid had assumed a brownish colour, but this gradually disappeared altogether after the tube had cooled down; and when the latter was opened after the lapse of some days, there was no pressure of gas, nor did the liquid exhibit the slightest acidity. In this instance the decomposition, probably resulting in the liberation of the nitrogen-oxides, was established by the continued exposure to 100°, and would doubtless, as in the case of the electric experiments, have gradually increased if the application of heat had been continued until the internal development of heat had resulted in explosion.

The difference in the behaviour of nitroglycerine and gun-cotton, when exposed to the influence of a source of heat (apart from the difference in the heat required for their explosion), is evidently due principally to the difference in their physical condition. When a heated body is applied to nitroglycerine, the liquid nature of the latter leads to the distribution through its mass of the heat applied, with rapidity sufficient to render the *ignition* of the but slightly volatile liquid a matter of difficulty, even by the application of a very highly heated body, such as a red-hot wire or rod, or a piece of burning wood; and when the liquid is actually inflamed it burns at first non-explosively, because the increase in temperature of the body of liquid (or of that part presented by the burning surface) which is necessary for developing its sudden decomposition or explosion, takes place only gradually. But if by establishment of a slow decomposition throughout or in some portion of the nitroglycerine, a tendency to disruption of the constituent molecules is developed, the disturbance of chemical equilibrium favours the action of any impulse from without, such as the direct application of heat, so that the *violent explosion* or sudden decomposition of the mass is determined by applying heat to an extent which would, under normal conditions, be quite inadequate to bring about such a result.

In the case of the solid and badly conducting substance gun-cotton, when a source of heat just sufficient for its ignition is applied to any portion, the heat is not diminished by distribution through the mass, hence the particles of gun-cotton contiguous to the source of heat are inflamed almost immediately. If the gun-cotton be in a loose or porous condition (*e. g.* in the form of wool or of loosely wound thread), the entire mass will inflame with such rapidity as to produce a species of explosion, on account of the rapid penetration to the surrounding particles of the heat resulting from the first ignition; but if it be in a compact (compressed) mass, in which the contiguity of particles more nearly approaches that of the particles in the liquid nitroglycerine, the gun-cotton proceeds to burn gradually from the exterior towards the centre of the mass.

If gun-cotton be exposed to a source of heat *insufficient* for its ignition, the heat will gradually accumulate in those parts most contiguous to the source, spreading with comparative tardiness through the mass. A twofold result will then be obtained; heat eventually accumulates to an extent sufficient to establish chemical change in the mass, which becomes greatest near the source of heat, so that, if the application of the latter be not interrupted, the temperature requisite for ignition will be speedily attained in those portions: the result will, however, be no longer the simple inflaming of the gun-cotton with more or less rapidity, but an explosion will ensue, as in the case of nitroglycerine, the violence being proportionate to the heat which has accumulated, and to the extent to which a disturbance of chemical equilibrium has been established.

Frequent confirmations of this view have been obtained in the course of my investigations on the effects of heat upon gun-cotton. The violence of explosion of samples of gun-cotton confined in flasks with not very narrow

sion; and although, in his published description of these various methods, he refers to difficulties in developing explosion by those which relate to the simple application of flame or other heated body to the nitroglycerine, yet he refers the effect produced by the confined charge or the percussion-cap only to the heat developed by the ignition of these exploding agents.

The circumstance that nitroglycerine, or any preparation of that substance, may be violently exploded *when freely exposed to air*, by the explosion in contact with it of a small

---

necks which had been for some time previously undergoing decomposition (from long-continued exposure to temperatures considerably below its inflaming-point), was always very much greater than would have been the case had gun-cotton in the flasks been ignited by the momentary application of a highly heated body. It would appear, from temperature-observations carried on during experiments of this kind (Phil. Trans. vol. clvii. pp. 197, 223, 226), that in those instances the great violence of explosion was to be ascribed in part to the rapid accumulation of heat in the mass of gun-cotton when the decomposition had reached particular stages; but there can be no question that, at the period immediately preceding the explosion, the gun-cotton was in a state of high chemical tension, and readily susceptible of instantaneous chemical change throughout, just as a Rupert's drop is readily susceptible of violent mechanical disintegration; so that the passage from gradual to instantaneous and therefore most violent decomposition, would occur as soon as the accumulation of heat attained the point at which a sufficient disturbing impulse was imparted to the mass.

The following series of experiments appear confirmatory in their results of the conclusions drawn from the accidental results obtained in the experiments just alluded to.

A wide test-tube was filled to about one-fourth with gun-cotton, the mouth of the tube was left open, and the gun-cotton was inflamed by means of a platinum-wire heated by electricity. A faint explosion was the result, accompanied by a considerable body of flame, and a portion of the gun-cotton was projected from the tube unburned.

The experiment was repeated, the tube being immersed for several minutes in a water-bath at a temperature of 100° C., so that the gun-cotton was raised throughout to that temperature immediately before it was inflamed. The explosion was decidedly, though not very greatly, more vehement than before; the tube was not shattered.

A broad piece of thin platinum-foil, about 2 inches long, was attached by its two sides to copper wires leading to the poles of a battery, sufficient resistance being introduced into the circuit to prevent the foil from being raised to a higher temperature than 90°–100° when the circuit was completed. The wires were approached to each other, so that the strip of foil formed a species of tube open at both ends and down the side. A similar quantity of gun-cotton to that used in the preceding experiments was placed inside this tube, being therefore nearly surrounded by the foil. The whole arrangement was then introduced into a test-tube, like those used in the preceding experiments, and the voltaic circuit was completed. In the course of a few minutes the odour of decomposing gun-cotton was perceptible at the opening of the tube; faint nitrous vapours were soon afterwards observed, and within about fifteen minutes after the first application of heat, the gun-cotten exploded very sharply with only a faint flash, and the tube was shattered and violently dispersed.

The great violence of the explosion at Woolwich, in 1866, of about 140 lbs. of gun-cotton which had been exposed to elevated temperatures for ten months, and of which some packages, very imperfectly purified, were known to be in a state of decomposition at the time (Phil. Trans. vol. clvii. p. 243 *et seq.*), can scarcely be only ascribed to the circumstances that the gun-cotton had been closely packed in strong cases, and that the packages of gun-cotton were at a temperature of about 50° C. at the time of the explosion. When the decomposition, established in some small portion of the gun-cotton, had attained the condition resulting in explosion, a large quantity of the material was in a state of incipient change and, therefore, in a favourable condition for sudden metamorphosis; and this circumstance must have greatly contributed to the suddenness and consequent violence of the explosion.

confined charge of gunpowder, or of a detonating substance, while other modes of explosion by the application of heat or flame, which have been described by M. Nobel, only develope explosion under special conditions, points to a decided difference between the action of the two modes of ignition, and appears to indicate that it is not simply the heat developed by the chemical change of the gunpowder or detonating powder which determines the explosion of the nitroglycerine.

An experimental investigation of this subject has left no doubt on my mind that the explosion of nitroglycerine through the agency of a small detonation is due, at any rate in part, to the mechanical effect of that detonation, and that this effect may operate in exploding the nitroglycerine quite independently of any direct action of the heat disengaged by the gunpowder or other detonating charge.

I was led to examine into this question by an interesting and important observation recently made by my Assistant, Mr. E. O. Brown, in connexion with gun-cotton. The fact that the violent explosion of this substance cannot be developed except when it is confined in receptacles of some strength has been up to the present time accepted as indisputable. It occurred, however, to Mr. Brown that as gun-cotton is analogous in its nature and operation as an explosive agent to nitroglycerine, differing principally from that substance in the rapidity and consequent violence of its explosion, it might also, like nitroglycerine, be susceptible of violent explosion when unconfined, by being ignited through the agency of detonation. This proved to be the case; for upon exploding a small charge of detonating powder in contact with, or in the immediate vicinity to, compressed gun-cotton freely exposed to air, instead of the latter being simply inflamed and then burning gradually, as would be the case if it were brought into contact with flame or any sufficient source of heat, it explodes with great violence, exerting a destructive action equal to that of nitroglycerine, and decidedly greater than that produced by gun-cotton when exploded under the conditions hitherto believed to be those most favourable to the full development of its explosive force. The explosion of a small mass of compressed gun-cotton in this manner suffices to determine the similarly violent and apparently simultaneous explosion of small detached masses of the same material, which may indeed be placed at distances of 0·5 to 1 inch from the original source of the explosion or from each other. Thus, rows of detached masses of gun-cotton, placed on the ground and extending 4 or 5 feet, have been exploded with most destructive results, by the firing of a small detonating tube in contact with the piece of compressed gun-cotton which formed one extremity of the row or train, the explosion of the entire quantity being apparently instantaneous and equally violent throughout.

In the first experiments instituted with the view of ascertaining the conditions to be fulfilled for ensuring the development of the violent action, or for accomplishing the detonation of gun-cotton, when perfectly unconfined, the following points were observed:—

1. If a confined charge of mercuric fulminate be placed in contact with, or buried in gun-cotton which is in the form of wool or spun yarn, its explosion does not develope the violent action of the gun-cotton, as would be the case if the latter were in the form of

a compact, hard and homogeneous mass (as obtained by submitting finely divided gun-cotton to powerful pressure). The light and loose gun-cotton is simply scattered with violence; portions of it are sometimes ignited by the flame of the exploding fulminate, the latter result being obtained with greater certainty, the less violent the detonation produced by the fulminate-charge.

2. The detonation of a small mass of compressed gun-cotton, freely exposed to air, by means of a mercuric fulminate-charge, does not accomplish the explosion of light gun-cotton-wool or yarn placed in immediate contact with it; the latter is scattered and partially inflamed, as in the preceding case*.

3. If the detonation of the fulminate-charge which is placed in contact with a mass of compressed gun-cotton is not sufficiently violent or sharp to effect the explosion, the solid mass is shattered and violently dispersed; if the detonation is upon the verge of that required for determining the violent explosion of the gun-cotton, no inflammation of the latter takes place; but if the explosion of the fulminate-charge is comparatively feeble, portions of the gun-cotton are inflamed at the moment of dispersion of the mass.

4. Explosive substances which are inferior to mercuric fulminate in the suddenness and consequent momentary violence of their detonation, cannot be relied upon to effect the violent explosion of freely exposed gun-cotton, even if employed in comparatively considerable quantities. Thus, even ordinary percussion-cap composition, which consists of a mixture of mercuric fulminate and potassic chlorate, cannot be used for the detonation of freely exposed gun-cotton unless a much more considerable amount be used than is necessary of pure mercuric fulminate for that purpose. Many other detonating mixtures, exploding less rapidly and violently than the above (*e. g.* very carefully prepared mixtures of sulphide of antimony, potassic ferro- and ferricyanides, plumbic ferrocyanide, and potassic picrate, with the chlorates), have been tried without success in very considerable quantities, as agents for developing the detonation of gun-cotton in open air.

5. The quantity of confined mercuric fulminate required to effect the detonation of freely exposed gun-cotton, is regulated by the degree to which the sharpness of its explosion is increased by the extent of accumulation of force, consequent upon the strength of envelope in which the fulminate is confined. From 1·3 to 2·0 grms. (20 to 30 grains) are required to detonate the gun-cotton, if the fulminate be confined in a thin case of wood, or in several wrapping of paper, while the same result can be produced with 0·32 grm. (5 grains) if that amount be confined in a cap of thin sheet metal.

If the fulminate be placed in a wide paper cylinder open at the top, which is rested upon the gun-cotton-surface, or if it be placed in a heap directly upon the surface of gun-cotton, and if in either instance the violent explosion of the fulminate be effected through the agency of a platinum-wire placed at the *base* of the heap, about 2 grms. (25 to 30 grains) of fulminate will also accomplish the detonation of the gun-cotton, the

* If two disks of compressed gun-cotton be firmly attached to opposite sides of the metal case which contains the minimum charge of fulminate required to produce detonation, when confined, the desired result will be produced; but if the disk be simply rested loosely against the sides of the metal case, they will only be violently thrown aside.

violent action of the fulminate being, in these instances, developed by the confinement of the portions first ignited in a weak envelope, which consists partly or entirely of the surrounding or superincumbent fulminate (see p. 491)*.

6. It need perhaps scarcely be stated that the degree of proximity of the detonating charge to the gun-cotton, which is essential for the explosion of the latter, is regulated by the violence of the detonation produced. 0·32 grm. (5 grains) of fulminate enclosed in a metal cap must be placed in close contact with (*i. e.* closely surrounded by) the unconfined gun-cotton, in order to effect its explosion, while 1·3 grm. (20 grains), similarly confined, will produce the same result if placed at least 0·5 inch distant from the surface of the compressed gun-cotton.

The foregoing facts appear to point to the mechanical action of a detonation as being the real cause of the violent explosion of freely exposed gun-cotton or nitroglycerine. At any rate they appear to indicate decisively that such explosion is not a result of the direct application of the heat developed by the explosion of the detonating materials. If it were so, then the detonating mixture described as percussion-cap composition, and other explosive mixtures, the ignition of which is attended by much greater development of heat than is obtained by the ignition of pure mercuric fulminate, should explode freely exposed gun-cotton more readily than the latter does; the readiness with which the gun-cotton is exploded should be solely proportionate to the amount of fulminate employed; and gun-cotton should be more readily exploded in the loose and open condition than in the compact and highly compressed form; for the latter presents it in the condition least favourable, and the former that most favourable to ready and rapid ignition by heat. Again, the actual temperature required for the explosion of nitroglycerine is very considerably higher than the exploding temperature of gun-cotton; the former may be heated to a temperature of 193° C. (380° F.) for some time without exploding, while the latter inflames at a temperature of 150° C., yet a much smaller charge (not more than 0·2 of the amount) of fulminate suffices for the explosion of unconfined nitroglycerine than it needed for the detonation of gun-cotton†. On the other hand, a quantity of confined percussion-cap composition which, if it were pure mercuric fulminate, would be altogether inadequate for the detonation of gun-cotton, suffices for the detonation of nitroglycerine.

Although the foregoing facts appear to afford indisputable evidence that the direct application of heat, from an exploding charge of detonating powder, is not concerned in developing the violent action of gun-cotton or nitroglycerine, an attempt has been made to devise some experiments in which the detonation of either of those substances by the agency described should be accomplished in such a manner as to interpose an effectual barrier between the material to be exploded and the heated gases or flame

* 3·24 grms. (50 grains) of the fulminate heaped upon the gun-cotton-surface as in the above experiments, but inflamed at the top of the heap, failed to explode or even to inflame the gun-cotton.

† About 3·24 grms. (50 grains) of *chloride of nitrogen*, confined by water, are required for the detonation of gun-cotton, whereas 0·1 grm. (1·5 grain) of the chloride, similarly confined, suffices to detonate nitroglycerine.

resulting from the ignition of the charge of fulminate destined to furnish the initiative detonation.

Some small pellets (0·5 inch in diameter) of compressed gun-cotton saturated with nitroglycerine were placed in a cylindrical wooden case open at one end and fixed at the bottom of a trough of water; the air-spaces between the separate pellets were thus occupied by water, the height of which above the charge was about one foot. An electric fuse, primed with 2·6 grms. (40 grains) of mercuric fulminate and rendered thoroughly waterproof by being coated with a cement composed of gutta percha and pitch, was weighted and placed at the bottom of the trough, on one side of the cylinder and at a distance of 2 inches from it. The detonation of the fulminate did not explode the charge; the experiment was then repeated, the water-space which intervened between the fuse and the wooden cylinder being reduced to 1 inch. In this instance the firing of the fuse exploded the immersed pellets, the water was projected to a great height, the trough was broken into small fragments, and a crater was formed in the ground upon which it rested. This experiment was repeated with the same results. A small cylinder about 1 inch in diameter and 2 inches long of compressed gun-cotton, saturated with nitroglycerine, was enclosed in a paper case, which was thickly coated with the gutta-percha cement. A screen of thin sheet copper, 4 inches square, was placed at the bottom of a trough and the waterproofed charge of explosive material was weighted and placed upon one side of the screen at 0·25 inch distance from it. A waterproofed electric fuse primed with 2·6 grms. (40 grains) of mercuric fulminate was placed on the other side of the screen at a distance of 1 inch from the latter; the trough was then filled with water, so that the screen, charge, and fuse were each surrounded and separated by the liquid. In the first experiment, the explosion of the fuse did not affect the charge, but upon repeating the experiment with a fuse placed at a distance of 0·75 inch from the screen, the charge was violently exploded as in the former experiment.

A precisely similar experiment was tried with cylinders consisting of compressed gun-cotton only, and enveloped in coatings of some thickness of the gutta-percha cement; but even when the charge and the fuse were placed close to the sides of the screen which separated them under water, the gun-cotton was not exploded by the detonation of the fulminate; the same negative result was obtained when a fuse (enveloped in the waterproof coating) was placed immediately upon a gun-cotton charge enclosed in the paper case and waterproof cement, and exploded under water or in open air. These negative results were instructive, as indicating that the thick yielding envelope which enclosed the gun-cotton charge (possibly assisted by the thin air-cushion by which the enclosed charge was also surrounded) served to protect the comparatively less sensitive explosive material, gun-cotton, by reducing or absorbing the power of the blow or concussion (or whatever the disturbing impulse may be). The same description of envelope did not protect the more readily explosive substance, nitroglycerine, as the preceding experiment showed.

A cylinder of gun-cotton, enclosed in a water-tight case of thin sheet metal, and

immersed in water, was violently exploded by a fulminate-fuse which was placed by its side, with about 0·25 inch of intervening water. In this instance, therefore, the exploding power of the fuse was not absorbed by the envelope which enclosed the gun-cotton.

Some nitroglycerine, contained in a glass beaker, was placed at the bottom of a trough filled with water; a fulminate-fuse, placed at a distance of 2 inches from the side of the beaker, failed to fire the nitroglycerine; but when the intervening water was reduced to little more than 1 inch, the detonation of the fuse exploded the nitroglycerine.

A 12-pound cast-iron shell (0·75 inch thick, and 4·45 inches internal diameter) was filled about one-half with small granules of gun-cotton impregnated with nitroglycerine. The shell was then filled with water, and a waterproof fulminate-fuse was inserted through the plug which closed the shell. The fuse and each separate granule of the explosive agent were therefore surrounded by water. Upon ignition of the fuse, the shell (which was placed in a very strong room) exploded with a violent report, and was broken into very small fragments, the greater number of which were buried in the timber which lined the cell.

A similar shell was half filled with the same explosive agent; the spaces between the granules and the empty portion of the shell were then filled with a thin plaster of Paris mixture, and a fulminate-fuse was imbedded in the solid plaster which filled the upper half of the shell. The explosion of the fuse was attended by a precisely similar result to that obtained in the preceding experiment.

It is believed that these experiments, together with the facts regarding the behaviour of gun-cotton which have been stated in the earlier part of this paper, afford convincing proof that the violent explosion of gun-cotton and nitroglycerine through the agency of a detonating fuse must be ascribed either to the mechanical effect of that detonation (*i. e.* to the work done upon the particles more immediately exposed to the blow or concussion of the detonation), or to the development of a disturbance of chemical equilibrium in the explosive agent by the suddenness and peculiar character of the concussion, or by the powerful vibrating impulse which the detonation establishes.

The readiness and certainty with which gunpowder, gun-cotton, and other explosive substances may be detonated through the agency of a blow from a hammer or a falling body, are regulated by several circumstances; they are in direct proportion to the weight of the falling body, to the height of its fall, or the force with which it is impelled downwards, to the velocity of its motion, to the mass and rigidity, or hardness, of the support or anvil upon which the body falls; to the quantity and mechanical condition of the explosive agent struck, and to the ready explosibility of the latter. Thus a sharp blow from a small hammer upon an iron surface will detonate gunpowder with very much greater certainty than the simple fall of a heavy hammer, or than a comparatively weak blow from the latter. It is very difficult, by repeated blows applied at very brief intervals, to ignite gun-cotton, if placed upon a support of wood or lead, both of which materials yield to the blow, the force set into operation by that blow being transferred through the explosive agent and absorbed in work done upon the material composing

the support. If, however, the latter be of iron, which does not yield permanently to the blow of the hammer, the detonation of these substances is readily accomplished. If the quantity of explosive agent employed be so considerable as to form a thick layer between the hammer and support, the force applied appears to be to so great an extent absorbed in the motion imparted to the particles of the compressible mass, that its explosion is not readily accomplished; and if the material be in a loose or porous condition (as, for example, in a state of powder or of loose wool), much work has to be accomplished in moving particles of the mass through a comparatively considerable space, and a second or even third blow is therefore required to determine its explosion.

These circumstances would appear to afford support for the belief that the detonation of an explosive material through the agency of a blow is the result of the development of heat, sufficient to establish energetic chemical change, by the expenditure of force in the compression of the material, or by the friction of the particles against each other, consequent upon a motion being momentarily imparted to them. It is conceivable that, from either of these causes, sufficient heat may be accumulated with almost instantaneous rapidity, in some portion of the mass struck, to develope sudden chemical change*. The circumstance, that the detonation of those portions of an explosive compound (such as gun-cotton or nitroglycerine) which are immediately between the surfaces of the hammer and the support is not communicated to the surrounding portions, may be ascribed to a combination of two causes, the instantaneous nature of the explosion, and the close confinement of the portions struck at the instant of their explosion. The mechanical effect of the detonation is absorbed by the masses of metal between which it occurred, and the gases developed disperse the surrounding portions of the explosive agent, as they rush away from between the two surfaces. It is possible also to detonate gunpowder and other explosive mixtures by a blow in such a manner that only the portions immediately struck are ignited; but those substances may also be exploded, though much less violently, by a less sudden or powerful application of force, in which case they detonate much more feebly; their explosion is accompanied by a larger volume of flame, and by the ignition of those portions which surround the part struck by the hammer.

The exceedingly violent motion of particles resulting from the sudden or extremely rapid transformation of a solid or liquid explosive body into highly expanded gas or vapour, must obviously exert a force which operates upon a resisting body, in the vicinity, in a manner precisely similar to the force applied by opposing a body in the

* In illustration of the effect of friction of particles of a mass against each other in determining the development of an explosion, the following experiment may be quoted. A very porous pellet of a mixture of potassic chlorate and amorphous phosphorus (carefully purified from ordinary phosphorus) was placed between two polished metal plates, and a somewhat rapidly accumulating pressure was then applied; the mass exploded almost directly, before, in fact, sufficient force had been expended to convert the loose aggregate of particles into a compact mass. A second similar pellet, also placed between two polished surfaces, was submitted to pressure very gradually and carefully applied, and was thus converted into a compact mass without being exploded; on afterwards submitting this to rapidly increasing pressure precisely as in the first experiment, a much more considerable accumulation of force was required to accomplish the explosion of the mass.

path of a solid mass which is set into very rapid motion. In other words, a detonation exerts a mechanical effect upon resisting bodies precisely similar to that of a blow, as from a falling hammer or a projectile propelled from a gun. Just as the force of a sufficiently sudden or powerful blow from a hammer is transformed into heat by the resistance to the motion of the hammer which the particles of an opposing body present, and by the consequent friction established between those particles, so the force or concussive action exerted by the matter set in motion when a solid or liquid is converted into gas or vapour, will also be transformed into heat, the development of which in an opposing body will be proportionate to the resistance to motion which its particles offer, and to the suddenness and violence of the concussion to which it is subjected.

The power of accomplishing the explosion or detonation of gun-cotton or nitroglycerine in open air through the agency of a detonation produced in its vicinity, would therefore appear to be correctly ascribable to the heat suddenly developed in some portion of the mass by the mechanical effect, or blow, exerted by that detonation, and would seem to be regulated by the violence and suddenness (either singly or combined) of the detonation, by the extent to which the explosive material is in a condition to oppose resistance to the force, and by the degree of sensitiveness of the substance to explosion by percussion.

The following points appear to support this view:—

1. Gun-cotton, freely exposed, cannot be detonated by any explosive agent less sudden and violent in its action than mercuric fulminate. Explosive mixtures (such as percussion-cap composition, see page 498, and mixtures of potassic chlorate with potassic picrate, &c.) which are apparently but little inferior to the fulminate in the rapidity of their explosive powers, will not detonate gun-cotton even though confined charges of them, amounting to about ten times the quantity of mercuric fulminate required to produce the effect with perfect certainty, are employed.

2. On the other hand, nitroglycerine, which is much more readily exploded by a blow than gun-cotton, may be detonated through the agency of explosive mixtures less violent and sudden in their action than the fulminate. A quantity of percussion-cap composition, about one-half that of the minimum of fulminate required to detonate gun-cotton, will suffice to detonate nitroglycerine.

3. If the suddenness of the detonation produced by means of mercuric fulminate be increased, as described at page 490, by its confinement in a strong envelope, a very much smaller quantity suffices to develope the detonation of gun-cotton than if the fulminate be exploded in open air, or in an envelope which offers but slight initial resistance.

4. The mechanical condition of the gun-cotton most materially influences the result obtained by its exposure to detonation. A considerable compactness or density, and a consequently great resistance to motion of the particles, is essential for the detonation of gun-cotton, as pointed out at page 497.

There are, however, several well-known facts, and some results of experiments instituted with special reference to this subject, which do not appear to be in harmony with the assumption that the detonation of nitroglycerine and gun-cotton in the manner

described is simply due to the *suddenness* of the development and application of physical force. The following are some of the more important facts of this kind:—

1. The circumstance that the explosion of mercuric fulminate accomplished the detonation of gun-cotton, whereas explosive agents less sudden in their action failed to furnish this result, appeared to render it probable that silver-fulminate, which explodes more suddenly and with much more powerful local force when applied under the same conditions, would accomplish the detonation of gun-cotton more readily than the mercury-compound, *i. e.* it was anticipated that a larger amount of the latter would be needed, than of silver-fulminate, to produce the desired effect. This proved, however, not to be the case; though apparently not inferior, the silver compound is in no way superior to that of the mercuric fulminate. The minimum quantity of the latter which can be relied upon to detonate compressed gun-cotton is 0·324 grm. (5 grains), and it is necessary to enclose that quantity in a case of stout sheet metal, and to place it in close contact with the gun-cotton in order to obtain the desired result (see page 499). 0·324 grm. (5 grains) of silver-fulminate enclosed in tin-foil, though it appeared to produce quite as sharp a detonation as the corresponding quantity of mercury-salt confined in the stout case, did not explode gun-cotton with which it was closely surrounded, but merely shattered and dispersed the mass. But when enclosed in the stout sheet-metal cap, the 0·3 grm. of silver-fulminate accomplished the detonation of gun-cotton.

2. Iodide of nitrogen, as one of the most sensitive and, apparently, violently explosive compounds with which we are acquainted, was next experimented with. The susceptibility to sudden explosion even of silver-fulminate will not bear comparison with that of the iodide of nitrogen or of the corresponding chlorine compound, though, as regards the mechanical effect of the explosion (*i. e.* its local destructive action) both of those compounds accomplished decidedly less work than the silver-fulminate under the same conditions (see page 508).

Many unsuccessful attempts have been made to explode gun-cotton through the agency of iodide of nitrogen. Pellets of this substance (weighing about 0·2 grm. and 0·35 grm.*), resting upon paper or thin cardboard, were carefully placed, when perfectly dry, upon compressed gun-cotton, and were then exploded by being touched with the end of a long rod; the compact masses of gun-cotton were more or less disintegrated by the explosions, but no detonation resulted. Indications having been obtained that the violence of explosion of the iodide was decidedly increased by its confinement (see p. 492), two descriptions of small shells charged with the substance were prepared. About 1 grm. of the iodide was placed, while moist, in a small cup of plaster of Paris, a spherical mass of the plaster was then formed round this, so that after a time the explosive agent was enclosed in a hard shell, the walls of which were about 0·3 inch in thickness. The shells thus produced were confined for several days in proximity to a desiccating agent, until it was found by trial of the shells that the perfect desiccation of the iodide of

* The weights of the masses of iodide of nitrogen used were estimated by first ascertaining the average loss sustained by desiccation of the substance after gentle pressure between bibulous paper, and making allowance for this loss in the quantities of iodide set aside to dry for experiment.

nitrogen through the porous plaster shell has been accomplished. These shells were then allowed to fall from heights of 4 feet and 20 feet upon masses of compressed gun-cotton; their explosion simply shattered the latter.

Short tubes of stout sheet copper open at one end only, were charged with 0·75 grm. of the moist iodide, and they were then closed with thick plugs of plaster or of tightly compressed bibulous paper. When the moisture had been entirely abstracted from the enclosed iodide through the porous plugs, the shells were carefully transferred to the surfaces of pellets of compressed gun-cotton, placed under the lower opening of a vertical iron pipe 20 feet in height, and a weight was allowed to fall down the pipe upon them. The shells exploded violently and were broken up and dispersed; but no detonation of the gun-cotton was effected. The same negative result was obtained with a similar shell charged with 1 grm. of the iodide.

6·5 grms. (100 grains) of this substance were pressed firmly together while moist, and heaped upon the upper surface of a pellet of compressed gun-cotton 1·25 inch in diameter, which rested upon a flat copper plate 0·05 inch thick. This plate was placed upon a thick layer of pumice-stone fragments, saturated with concentrated sulphuric acid. This arrangement was situated in open air, and was enclosed under a box which could be readily and quietly withdrawn from a distance by means of a cord; immediately over it was fixed a small vessel containing sand, which could be discharged so as to fall upon the iodide of nitrogen by the pull of a string. After the lapse of five days (during dry weather), when it was judged that the iodide of nitrogen had dried, the box was withdrawn and the sand allowed to fall; a very sharp explosion was the result, but it was evident from the character of the sound that this was due to the explosion of the iodide only. The gun-cotton pellet was found to have retained sufficient moisture (absorbed from the iodide) to interfere with its explosibility; the result of the experiment was therefore not decisive, but it afforded an excellent illustration of the force exerted by the explosion of that quantity of iodide of nitrogen. The stout copper plate upon which the pellet rested was bent into the shape of a watch-glass; the gun-cotton pellet (which had been produced from the pulp by a pressure of about four tons on the square inch) was driven into the plate so as to indent the latter considerably, and a sharp impression of some small indentations existing upon the copper surface was found upon the lower surface of the pellet.

The foregoing experiment was repeated with this difference, that the charge of iodide of nitrogen was placed in a flat-bottomed capsule of very thin platinum-foil, the lower surface of which was in close contact with the pellet of compressed gun-cotton. The latter was placed upon a flat copper plate (precisely similar to that used in the preceding experiment), which rested upon a thick layer of fused chloride-of-calcium fragments.

After a lapse of five days the box which covered this arrangement was withdrawn and the iodide was exploded as before, without accomplishing the detonation of the gun-cotton. As in the former instance, the compressed pellet was driven into the copper plate and moulded to the cup-shaped indentation produced. The gun-cotton proved in

this instance to be perfectly dry; this experiment therefore demonstrated decisively that the detonation could not be accomplished even by so large a quantity as 6·5 grms. of iodide of nitrogen.

3. The following experiments were made with chloride of nitrogen, for the purpose of comparing its power to accomplish the detonation of gun-cotton with that of the explosive agents already discussed. About 0·65 grm. (10 grains)* of the chloride were transferred to a thin watch-glass and covered with a film of water (see p. 492); the watch-glass was placed upon the upper surface of a pellet of gun-cotton which rested upon the ground. The chloride of nitrogen was then exploded by means of a long rod the extremity of which was moistened with turpentine. The glass was shattered and dispersed by the explosion, but the mass of gun-cotton was only to a slight extent disintegrated. 1 grm. (15·4 grains) of the chloride was next employed in precisely the same manner; the gun-cotton pellet was not exploded, but was much shattered by the explosion. About 2 grms. (31 grains) of the chloride, applied as before, did not explode the gun-cotton, but the pellet was completely broken and violently scattered. A corresponding quantity of the chloride, of which the surface was directly exposed to air, broke the watch-glass into numerous fragments, but did not in any way affect the gun-cotton pellet, which was not even moved from its original position. 3·25 grms. (50 grains) of the chloride were next employed in the same manner as the foregoing charges (*i. e.* contained in a thin watch-glass and covered with a film of water); in this instance the gun-cotton was detonated by the explosion of the liquid. The experiment was repeated with what was estimated to be the same quantity of chloride of nitrogen; the gun-cotton pellet was not exploded, but was completely disintegrated and scattered, the effect being the same as that produced with an amount of mercuric fulminate just below that required to accomplish the detonation of gun-cotton. It would appear therefore that 3·25 grms. (50 grains) of chloride of nitrogen, covered with water, is about the minimum quantity required to accomplish the result attainable with 0·32 grm. of mercuric fulminate enclosed in a metal case.

The foregoing results obviously do not support the view that the suddenness or sharpness of a detonation alone favours the development of violent explosive force from gun-cotton in open air. The silver-fulminate produces a much sharper explosion than the mercuric fulminate, yet it was not found that a smaller quantity of the former than of the latter was required for the detonation of gun-cotton. The explosion of the iodide and the chloride of nitrogen is certainly more sudden than that of the above fulminates, unconfined, and at any rate equally so with the confined fulminates; yet it was not found possible to detonate gun-cotton by the explosion of 6·5 grms. (100 grains) of the iodide, in contact with it, and 3·24 grms. (50 grains) of chloride of nitrogen, *confined by water*,

* The weights of the quantities of chloride of nitrogen employed were closely estimated by ascertaining the weight of corresponding volumes of liquid having the same specific gravity as the chlorine compound. In the experiments with chloride of nitrogen, I had the advantage of assistance from my friend Professor Bloxam.

were required to accomplish the result attained by 0·32 grm. of either of the confined fulminates, or by 2 grms. of the mercuric fulminate, unconfined by any strong envelope (p. 499).

With the view of ascertaining whether the relative power of different explosive agents to accomplish the detonation of gun-cotton appears to be in direct proportion to the relative mechanical effects of their explosion (*i. e.* to the work performed by them upon a body placed in contact with them), a series of experiments was instituted with the object of comparing this particular action of the several explosive materials.

A thin and uniform copper sheet was cut up into square pieces of equal dimensions, and these were similarly supported at their corners only. Equal quantities of the four different explosive agents, the mercury- and silver-fulminates and the chloride and iodide of nitrogen, were employed; in the case of the two former the weights were directly determined, but in the case of the latter they were estimated as accurately as possible by the methods given at pages 504 and 506. In some experiments the fulminates were placed in direct contact with the copper, in others, with the view of comparing them accurately with the iodide of nitrogen, they were placed upon thin cards which rested upon the sheet copper. The iodide of nitrogen was always used in this way, but as for obvious reasons the chloride of nitrogen could not be thus employed, it was placed in very thin watch-glasses which rested upon the copper sheet. The force brought to bear upon the copper support was obviously not diminished to any important extent by the expenditure necessitated in the fracture of the thin glass surface.

The following are the results deduced from repeated experiments with a series of different proportions of the several explosive agents.

The mechanical effect of the explosion of silver-fulminate in small quantities, *freely exposed to air*, was decidedly greater than that of the other three substances when exploded under the same conditions. 0·07 grm. (1 grain) of this fulminate produced a deep and very sharply defined indentation in the copper sheet. A corresponding quantity of the iodide of nitrogen, made to cover about the same surface of the sheet metal, produced a decidedly less deep and more rounded indentation. The explosion of an equal quantity, and even more than double that amount, of chloride of nitrogen, with its surface freely *exposed to air*, did not even break the thin watch-glass which contained it; if, however, similar quantities of the liquid were covered with a thin layer of water, their mechanical action upon the copper was decidedly greater than that of the exposed iodide. 0·07 grm. (1 grain) of mercuric fulminate, freely exposed, produced no effect whatever upon the copper sheet, but if enclosed in a thin case of sheet metal, its mechanical action was greater than that of silver-fulminate when exposed to air. 1 grm. (15·5 grains), 1·62 grm. (25 grains), and 3·24 grms. (50 grains) were exploded without producing any indentation upon the copper, provided that the little heap was inflamed by the application of a heated body to some portion of their *exposed* surfaces; but if the source of heat was situated at the base of the heap, being entirely enclosed by the fulmi-

nate, a very sharp explosion was produced instead of a dull muffled report, and the mechanical effect upon the copper approached in extent that produced by corresponding quantities of chloride of nitrogen confined by a thin layer of water, though it was still much inferior to that produced by freely exposed silver-fulminate, exploded by its surface being touched with sulphuric acid. The destructive effect of the mercuric fulminate was still further increased by placing the charge in a short wide paper cylinder, freely open at the upper end, and with the source of heat (platinum-wire) buried deeply in the charge (see p. 498). But the mechanical effects produced by mercuric fulminate, exposed to air and inflamed from beneath as described, were not to be compared to those obtained by enclosing it in cases of sheet metal. 0·15 grm. (1 grain), thus confined, produced an effect upon the copper sheet somewhat greater than that of a corresponding quantity of the silver-fulminate, freely exposed; and a charge of 0·32 grm. (5 grains), similarly confined, was about equal in violence of action to 1 grm. (15 grains) of the unconfined material inflamed at the base of the heap. A comparison of the effects of larger quantities of the several explosive agents confirmed the foregoing results. Thus 0·28 grm. (4 grains) of unconfined chloride of nitrogen exerted much less destruction than an equal quantity of unconfined iodide of nitrogen; but if the former was confined by a thin layer of water, it was considerably more violent in its action than a corresponding quantity of the unconfined silver-fulminate. The 0·28 grm. (4 grains) of mercury-salt produced no effect upon the copper support; but a similar quantity confined in a metal tube, exerted a destructive action about equal to that of the unconfined silver-fulminate.

1 grm. of iodide of nitrogen and a similar quantity of chloride of nitrogen, covered with a film of water, did no more work than 0·5 grm. of unconfined silver-fulminate; and the effect of the latter was exceeded by that of a similar quantity of the mercury-salt confined in a stout sheet-metal cylinder, while 1 grm. of the latter, freely exposed but inflamed at the base of the heap, exerted a destructive action somewhat inferior to that of the enclosed chloride of nitrogen.

It would appear, therefore, from these experiments, that, when unconfined, the violence of explosion of chloride of nitrogen is less than that of the iodide, and that, if confined under water, it very considerably exceeds that of the exposed iodide, but falls very short of that exerted by unconfined silver-fulminate. It also appears that the mercuric fulminate, which is much less rapidly explosive than either of the other substances, exerts less mechanical force than any of them, if freely open to air, and if inflamed at some portion of the exposed surfaces; if ignited at the lower inner portion of the mass, where the part first inflamed is enclosed by the mass of the material itself, it exerts a destructive force little inferior to that of the chloride of nitrogen enclosed by water; but if confined in a strong envelope (*e. g.* of sheet tin), the mercuric fulminate is greater in violence of action than the unconfined silver-fulminate.

These results to a great extent confirm the correctness of the view that the readiness with which the detonation of gun-cotton is accomplished is in proportion to the mecha-

nical force exerted by the initiative detonation to which it is subjected. The force exerted by small quantities of strongly confined silver- and mercuric fulminate greatly exceeds that developed by the explosion of comparatively large proportions of the iodide and chloride of nitrogen. This may be accepted as accounting, to some extent, for the fact that the detonation of gun-cotton could not be accomplished by an amount of iodide of nitrogen twenty times greater than that of fulminates required for the purpose, while ten times the quantity of the confined chloride were required to produce the result. That the quantity of mercuric fulminate required to produce detonation is reduced in proportion as means are applied to increase the violence of the force exerted by it at one time, is quite in accordance with the above view.

Several curious and apparently anomalous effects were, however, observed in the course of the numerous experiments referred to in this paper, which suggest the inquiry whether there may not be some peculiarity in the concussion or powerful vibration produced by a particular kind of explosion, which acts apart or distinct from the mechanical force of that explosion in developing or promoting the detonation or sudden chemical disintegration of the molecules of a neighbouring explosive body.

The results of a few experiments instituted with nitroglycerine appear to furnish a decided affirmative reply to that inquiry. A comparison was in the first instance instituted between the mechanical action of the explosion of nitroglycerine, and of the other materials which have been discussed. The charges of nitroglycerine were introduced into small wide tin tubes, freely open at the upper end or closed by means of a cement, and their explosion was accomplished by the detonation of a small percussion-cap, just immersed in or resting upon the liquid, and containing 0·07 grm. (1 grain) of mercuric fulminate. Nitroglycerine thus detonated produced a destructive effect upon the copper support very greatly exceeding that obtained with the same amount of unconfined silver-fulminate. As the mechanical force developed by nitroglycerine was so very considerable, and as, moreover, the character of its detonation might be expected to bear some analogy to that of gun-cotton, it was considered probable that the latter might prove susceptible of detonation by a much smaller proportion of nitroglycerine than it is necessary to employ of the confined fulminates. No success, however, attended repeated attempts to explode gun-cotton by the detonation of 0·07 grm. (1 grain) and increasing charges up to 0·65 grm. (10 grains) of nitroglycerine. At the same time these results were not quite conclusive, as it was not found easy to ensure the complete detonation of the liquid by the small fulminate-charge, on account of the difficulty of securing a favourable adjustment of the detonating cap and the very small quantity (from two to ten drops) of nitroglycerine used. The experiments were therefore repeated with corresponding quantities of the liquid converted into a thick paste by admixture with sand, in tin tubes similar to those previously used. The explosion of the nitroglycerine appeared to be rendered more certain by this contrivance, but in order more thoroughly to ensure its proper detonation, the charge of mercuric fulminate used for that purpose was increased to 0·14 grm. (2 grains). Still the detonation of gun-cotton could not be ac-

complished, although the charge of nitroglycerine was gradually increased to 1 grm. The disk of compressed gun-cotton which rested upon a support of wood was shattered almost to dust, portions being driven deeply into the wood, which exhibited an indentation corresponding to the form of the disk. In order to compare the mechanical effect of the detonation of nitroglycerine with that of the strongly confined fulminates, 0·65 grm. (10 grains) of the liquid were placed in the small tin tube upon stout sheet copper and detonated by means of 0·14 grm. (2 grains) of mercuric fulminate; the work done upon the copper resembled in extent that accomplished with a corresponding charge of the confined fulminate (double the amount required to effect the detonation of gun-cotton). It appeared evident, therefore, that some power, apart from violence of explosion, was wanting in nitroglycerine to produce the result obtained with the fulminate. With a view to obtain still more decided evidence on this point, the experiments were continued upon a larger scale. Some four-ounce (124·5 grms.) disks of compressed gun-cotton were placed upon thick supports of wood, and confined charges of nitroglycerine, weighing about 0·75 ounce (23·3 grms.), were placed upon these disks and successively exploded. The pieces of wood were more or less shattered; they were deeply indented (the circumference of the disk being clearly imprinted upon them), and the gun-cotton was pulverized and violently scattered, portions being driven firmly into the wood, but the desired result was not in any instance accomplished. As a last experiment, the wooden support bearing the disk of gun-cotton with the vessel containing (23·3 grms.) 0·75 ounce of nitroglycerine, was buried about 6 inches in the ground, the stiff clay soil being firmly pressed over the whole. The explosion of the nitroglycerine threw the earth up violently, the piece of timber was split across the fibre and shattered in the centre, and the gun-cotton, in a fine state of division, was found disseminated in the earth and partly forced into the wood *.

In contrast to the foregoing results, it may be mentioned that small perforated cylinders of compressed gun-cotton, weighing 7·75 grms. to 15·5 grms. (0·25 oz. to 0·5 oz.), with the usual small confined charge of mercuric fulminate inserted into the perforation, have frequently been employed, and invariably without failure, for effecting the detonation of a large disk or slab of gun-cotton, or of a number arranged side by side in open air, by simply placing them upon or against any one of the surfaces of the larger mass of gun-cotton. It should also be stated that the detonation of a small quantity of nitroglycerine has been found to accomplish the simultaneous explosion of surrounding charges of that substance closely confined in small vessels of sheet tin, and placed at distances of 2 or 3 inches from the central charge. Lastly, it was found that the detonation of 7·75 grms. (0·25 ounce) of gun-cotton determined the explosion, simultaneously with it, of a charge of nitroglycerine confined in a vessel of sheet tin and placed at a distance of 1 inch from the gun-cotton, while 15·5 grms. (0·5 ounce) of the latter produced the same result when separated from the confined nitroglycerine by a space of 3 inches. All these experiments were so conducted that indisputable evidence was

* These experiments were repeated with 1 ounce of nitroglycerine, with the same results.

obtained when the charges had been exploded, or were merely scattered, by the force of the detonating charge. It was found in every instance quite impossible to distinguish any difference in the suddenness or sharpness of the report produced when the detonating charge alone was exploded, and when it accomplished the simultaneous firing of neighbouring charges.

The results obtained with nitroglycerine in attempts to detonate gun-cotton through its agency, appear to me to substantiate the view which has obtruded itself repeatedly on my mind upon consideration of many of the phenomena observed in the experiments detailed in this communication, namely, that a particular explosion or detonation may possess a power of determining at the instant of its occurrence similarly violent explosions in distinct masses of the same material, or in contiguous explosive bodies of other kinds, which power is independent of, or auxiliary to, the direct operation of mechanical force developed by that explosion; that, as a particular musical vibration will establish synchronous vibrations in particular bodies while it will not affect others, and as a chemical change may be wrought in a body by its interception of only particular waves of light, so some kinds of explosions or powerful vibratory impulses may exert a disturbing influence over the chemical equilibrium of certain bodies, resulting in their sudden disintegration, which other explosions, though developing equal or greater mechanical force, are powerless to exercise. Thus the mechanical force developed by the explosion of 3·25 grms. (50 grains) of chloride of nitrogen far exceeds that exerted by the explosion of 0·32 grm. (5 grains) of the strongly confined fulminates, yet, in their effects upon gun-cotton, the substances in question are not on an equality unless employed in about those proportions. It appears, therefore, that it is necessary to increase greatly the mechanical force of the explosion to obtain the desired result with chloride of nitrogen, in order to compensate for the deficiency or absence of some peculiar power possessed by the explosion of the fulminates. Again, in the case of nitroglycerine, we have a body which explodes with a development of force quite as great as that of the strongly confined fulminates, yet the detonation of gun-cotton could not be accomplished by the explosion in close contact with it of a quantity of nitroglycerine more than sixty-five times greater than the amount of mercuric or silver-fulminate required for that purpose. Do not these facts appear to demonstrate the existence of a remarkable difference in the *character* of the concussions or vibrations produced by exploding the two materials?

I venture to offer the following as being the most satisfactory explanation which occurs to me of the remarkable differences just pointed out in the behaviour of different explosive agents. The vibrations produced by a particular explosion, if synchronous with those which would result from the explosion of a neighbouring substance which is in a state of high chemical tension, will, by their tendency to develope those vibrations, either determine the explosion of that substance, or at any rate greatly aid the disturbing effect of mechanical force suddenly applied, while, in the case of another explosion which produces vibrations of different character, the mechanical force applied by its agency has to operate with little or no aid; greater force or a more powerful detonation

must, therefore, be applied in the latter instance, if the explosion of the same substance is to be accomplished by it.

The power possessed by the violent explosion of a particular material (such as gun-cotton or nitroglycerine) to determine the apparently simultaneous explosion of perfectly separate masses of the same substance, does not excite surprise. Instances of the apparently simultaneous explosion of numerous distinct and even somewhat widely separated masses of explosive substances (such as simultaneous explosions in several distinct buildings at powder-mills) do not unfrequently occur, in which the generation of a disruptive impulse by the first or initiative explosion, which is communicated with extreme rapidity to contiguous masses of the same nature, appears much more likely to be the operating cause, than that the simultaneous explosion should be brought about by the direct operation of heat and mechanical force developed by the starting explosion. In submitting this proposition I confidently believe that I am not advancing a view which possesses any claim to novelty, but that I am only contributing some support, by the result of experiment, to an opinion which has been strongly entertained by many.

It appears remarkable that two substances so analogous as gun-cotton and nitroglycerine in their chemical constitution and general characters as explosive agents, should exhibit the very great differences which have been observed in their susceptibility to explosion by the effects of a detonation. An explosive mixture (such as percussion-cap composition) which will not detonate gun-cotton if used in considerable quantities and strongly confined, explodes nitroglycerine even if used in as small proportion as 0·2 grm. (3 grains); 0·32 grm. (5 grains) of the strongly confined fulminates is required to detonate gun-cotton, while 0·07 grm. (1 grain), and perhaps even less, will explode nitroglycerine. The detonation of gun-cotton by means of chloride of nitrogen can only be accomplished by employing about 3·25 grms. (50 grains) of that substance, while 0·1 grm. (1·5 grain) suffices for the explosion of nitroglycerine. It is obvious from these results that a comparatively very small amount of mechanical force, suddenly applied, suffices to develope the violent decomposition of nitroglycerine; it is therefore not difficult to understand why this substance, though incapable of detonating gun-cotton, even when used in considerable quantities, should be itself readily exploded by means of the latter. It was impossible to determine how small a proportion of gun-cotton would suffice for that purpose, because, in the necessary experiments, the gun-cotton would have to be placed in very close proximity to, or contact with, the nitroglycerine, in which case the fulminate-charge required for detonating the gun-cotton would alone much more than suffice for exploding the nitroglycerine.

The comparatively very great sensitiveness of this substance to explosion through the agency of a detonation may probably be ascribable in part to its physical character as a liquid, and in part to the fact that the proportion of oxygen to oxidizable elements is much more considerable in nitroglycerine than in gun-cotton.

In considering the manner in which a detonation operates in determining the violent explosion of gun-cotton and nitroglycerine in open air, I have, for the sake of simplicity, confined myself to an examination of the manner in which those particular explosive substances are affected by the disturbing agency in question. It must not, however, be supposed that the power to exert a violent explosive action, when unconfined or partly exposed to air, is limited to explosive *compounds*. A few experiments instituted with explosive *mixtures* (produced by the intimate incorporation of powerful oxidizing agents and readily oxidizable substances, the combustion of which furnishes gases or vapours) have demonstrated that the destructive or explosive force of these may also be fully developed under conditions most unfavourable to their operation as explosive agents, under ordinary circumstances, if they are submitted to the influence of *a detonation*. Mixtures of potassic chlorate with the sulphides of antimony or arsenic, with potassic ferro- or ferri-cyanide, with potassic picrate, and other explosive mixtures of similar nature, and lastly even gunpowder, have been readily made to explode, when unconfined, with the full force which they are capable of exerting, by being placed in contact with a confined charge of mercuric fulminate. As far as could be determined by small comparative experiments, the readiness with which the violent explosion of these mixtures can be developed is, as might be anticipated, in direct proportion to their sensitiveness to explosion by percussion. Thus a mixture of the potassic picrate and chlorate, freely exposed to air, is exploded apparently with as much facility as gun-cotton by the detonation of a small fulminate-charge, and the violence of the explosion approaches that of gun-cotton fired under the same conditions. The detonation of a freely exposed mixture of the chlorate with sulphide of antimony is somewhat less readily accomplished, and the violent explosion of gunpowder requires the fulfilment of special conditions favourable to the action of the detonating charge of fulminate. If the grains of a small charge of powder be merely heaped upon a flat surface, the case which contains the fulminate being inserted into the heap, they are simply scattered by the detonation of the fulminate; but if a corresponding quantity of gunpowder be so arranged that the dispersion of the grains is impeded (as by placing it in a cylinder quite open at the upper end), its violent explosion is accomplished with certainty.

The following experiment affords an illustration of the difference in effect between the ignition of gunpowder in the ordinary manner, and by detonation, under precisely similar conditions. A small iron cylinder (4 inches long, 0·15 inch thick, and 1 inch internal diameter, closed at one end) was inserted into heavy clay soil so that its opening was on a level with the surface, and the earth was firmly rammed round it. The cylinder was then filled with fine-grain gunpowder, into the centre of which an ordinary electric fuse (primed with meal powder) was inserted. When the latter was ignited, the powder exploded with a dull report, and the force was entirely directed upwards, no effect being produced upon the cylinder or upon its position in the ground. A second precisely similar cylinder, enveloped by earth in the same way, was filled with sand, into which was inserted an electric fuse primed with mercuric fulminate. The explosion of the

buried fuse did not displace the cylinder, but had the effect of bulging it somewhat in the centre and cracking it slightly in one place. A third similar cylinder was filled with gunpowder, and an electric fuse primed with a corresponding quantity of fulminate to that used in the preceding experiment, was inserted, the mouth of the cylinder being left quite open, as in the other instances. The explosion of the powder was attended by a sharp report, the cylinder was rent into several pieces, which were scattered about, and a cavity was formed in the ground, the earth being projected to a considerable distance. The effect was, in fact, similar to what would have been produced had the powder-charge been in a buried and tightly closed shell. Similar results were obtained in other experiments, confirmatory of the power possessed by a detonation to develope the explosive force of gunpowder, under conditions antagonistic to the violent action of the latter under ordinary circumstances.

The results of a few experiments instituted with small charges of gunpowder (8 ozs. and 1 lb.) appeared to furnish decisive indications that their explosion through the agency of a detonation was considerably more rapid than when flame was applied tc their ignition under corresponding conditions. The charges were enclosed in sheet-tin cases closely resembling each other, and these were buried in the ground at depths of 18 inches in holes of corresponding dimensions, the earth being rammed down tightly upon the charges in the same manner, and by the same operator, in each instance. They contained electric fuses which, on the one hand, were primed in the ordinary way with meal powder, and, on the other, with mercuric fulminate. In the instance of the ordinary fuses, the explosion of the charges produced clear holes, the earth being partly piled up around, and partly scattered; but in the case of the charges fired with detonating fuses, much of the earth was thrown up vertically with considerable violence, but there was very little scattering effect, the hole being to a great extent filled up again by the earth momentarily displaced*.

That the explosion of gun-cotton through the agency of detonation exerts a more violently destructive action than its explosion when strongly confined, by the simple agency of heat, has been abundantly proved by blasting operations in various descriptions of rock, and by measurement of the comparative destructive effect of charges exploded under water. Charges of gun-cotton contained in blast-holes, and having a detonating fuse inserted in or placed immediately over them, have produced much greater rending and shattering effects in hard rock and in wood (although the blast-holes were left entirely open, or only filled with loose sand, earth, or powdered rock) than corresponding charges applied in similar positions, but fired with ordinary fuses, although in the latter instances the gun-cotton was confined by "tamping," or firmly closing the blast-hole to a considerable depth. A series of systematic experiments have been carried on at Chatham by the Government Committee on Floating Obstructions,

* The relative displacing powers of powder-charges fired under similar conditions by the two modes of ignition has since been made the subject of practical experiments at the Royal Engineer Establishment, Chatham (Nov. 1869).

with the view of comparing the destructive power of gunpowder and gun-cotton, in which charges of these materials were exploded in proximity to submerged targets, with systematic variations of the strength of the cases containing the charges, the depth of their immersion beneath the surface, and their distances from the targets. The results of these experiments warranted the conclusion that gun-cotton, when confined in cases of sufficient strength to develope its full explosive action, exerted a destructive effect equal to about five times that of gunpowder. A few experiments to compare with these have been recently instituted with charges of gun-cotton enclosed in thin sheet-metal cases and exploded by means of detonating fuses, and in these the destructive action upon vertical targets, placed at very considerable distances from the charges, was from ten to twelve times greater than that of gunpowder. The concussion imparted through the water to considerable distances, by the explosion of small charges (2 to 3 lb.) of gun-cotton in the new manner, very greatly exceeded in their effects the results produced by the explosion of submerged charges by the ordinary method.

A series of experiments has been instituted with the object of ascertaining whether the remarkable results obtained by exploding gun-cotton through the agency of a detonation were in any way ascribable to a peculiarity in the results of the metamorphosis. Known weights of gun-cotton have been exploded *in vacuo* by means of a small detonating fuse, and the volume of gas produced accurately determined. After deducting the volume furnished by the fuse employed, the results obtained corresponded very closely to those furnished by exploding shells, charged with gun-cotton, through the agency of a heated platinum-wire, under precisely similar conditions. The products of explosion of the detonated gun-cotton have been submitted to complete analysis, and the results (which will be given in detail in a memoir "On the Results of Explosion of Gun-cotton" which I hope shortly to submit to the Royal Society) did not differ in any very important respect from those obtained by the most complete metamorphosis of the substance when exploded in strong shells under ordinary conditions. As the chemical change sustained by the decomposition of gun-cotton, when exploded through the agency of a detonation, cannot be said to differ in completeness from that consequent upon a fulfilment of the ordinary conditions essential to the development of its full explosive force, the increased destructive effect developed by the explosion of gun-cotton through the agency of a detonation must obviously be ascribed to the greater rapidity of its explosion under these conditions. This conclusion appears to receive confirmation from some of the results of a series of practical blasting operations which I have recently conducted at Allenheads, in conjunction with THOMAS SOPWITH, M.A., F.R.S., from which it appeared that, while the splitting and shattering effects upon hard rock was much greater with "detonated" gun-cotton than with charges of this material exploded in the ordinary way, the displacement or projection of the broken rock appeared decidedly less considerable*. Again, the work accomplished in the way of displacement in a comparatively soft and yielding material, such as a very friable rock (*e. g.* chalk or soft limestone), is less

* These results are borne out by recent experiments at Portsmouth upon the demolition of fortifications.—*November* 1869.

considerable than when the more gradual explosion of gun-cotton is brought about by the usual mode of firing. In the case of the detonation of gun-cotton imbedded in such material, the force which is applied with comparative suddenness is to a considerable extent expended in the disintegration and compression of the surrounding material, before there is time for motion to be communicated through any considerable mass of the rock.

A further indication of the difference in the rapidity of explosion of gun-cotton by detonation and by the simple application of heat is furnished by the difference in the luminous effect observed in the two instances. The ordinary explosion of gun-cotton is attended by a considerable body of flame, due to the ignition of the generated carbonic oxide; but the detonation of gun-cotton is only attended by a sudden flash, which it is very difficult to observe in daylight if only small quantities are exploded. The transformation of the solid into gas appears, in fact, to be too sudden for the generated combustible gas to become inflamed.

In conclusion, it may not be out of place to refer briefly to a few illustrations of the important bearings which the new mode of developing the explosive force of gun-cotton has upon the practical uses of the material as a destructive agent. The confinement of a charge of gunpowder or gun-cotton in a blast-hole, by firmly closing up the latter with earth, powdered rock, or other compressible material (by the process known as tamping or stemming) to a depth greater than the line of least resistance opposed to the action of the charge, is essential to the success of a blasting operation; but the great rapidity of explosion, by detonation, of a charge of gun-cotton greatly reduces the value of this operation; the destructive effect of the material, when exploded in a hole which is left open, is not inferior in extent to that obtained by similarly exploding a charge confined in the usual manner. Thus the most dangerous operation in connexion with blasting may be entirely dispensed with*. In submarine operations, it is no longer necessary to enclose the charge of explosive agent in the strong and therefore cumbersome metal receptacles hitherto required to ensure the full development of its explosive force; the destructive action of a charge of gun-cotton, enclosed in a waterproof bag or thin glass vessel and exploded by detonation, being decidedly greater than that furnished by a corresponding charge confined in a strong iron vessel and exploded by flame. Small charges of gun-cotton simply resting upon the upper surfaces, or loosely inserted into natural cavities, of very large masses of the hardest description of rock or of iron, have broken these up as effectually as if corresponding charges had been firmly imbedded in the centre of the mass and exploded in the usual manner. Lastly, the certainty, facility, and expedition with which certain important military destructive operations may be accomplished by means of gun-cotton exploded by detonation, are not among the least important advantages which are now secured to this interesting and remarkable explosive agent.

* This observation does not apply equally to large charges, such as are used in some military operations, for the placing of which it is necessary to sink or drive shafts or openings of large dimensions.